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Cost and Performance Report

(EW-200932)

Demonstration and Validation of a Waste-to-Energy Conversion System for Fixed DoD Installations

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ACRONYMS AND ABBREVIATIONS

ABW	Air Base Wing
AC	alternating current
AFB	Air Force Base
AFTCC	Air Force Flight Test Center
ARB	Air Resources Board
ASTM	American Society for Testing and Materials
BACT	Best Available Control Technology
BTU	British thermal unit
C&D	construction and demolition
CARB	California Air Resource Board
CCR	California Code of Regulation
CDW	Construction and Demolition Waste
CE	Civil Engineering
CFR	Code of Federal Regulations
CO	carbon monoxide
COTS	commercial off-the-shelf
DoD	Department of Defense
EC	electrical conductivity
EKAPCD	Eastern Kern Air Pollution Control District
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FY	Fiscal Year
g/bhp-hr	grams per brake horsepower - hour
GC-FPD	Gas Chromatography with Flame Photometric Detector
GCV	gross caloric value
GEM	Green Energy Machine
GHG	greenhouse gas
HC	hydrocarbon
HVAC	heating, ventilation, and air conditioning
HX	heat exchanger
I/O	input/output
ISO	International Organization for Standardization
IST	Infoscitex Corporation
kJ/kg	kilojoules per kilogram

ACRONYMS AND ABBREVIATIONS (continued)

kW_e	kilowatt (electrical)
kWh	kilowatt hour
kW_T	kilowatt (thermal)
LOE	level of effort
MBAL	Main Base Active Landfill
mg/L	milligrams per liter
mg/kg	milligrams per kilogram
MRE	meal-ready-to-eat
MSW	municipal solid waste
MSW Power	MSW Power Corporation
MW_e	megawatt (electrical)
MW_T	megawatt (thermal)
NMHC	non-methane hydrocarbon
NO_X	nitrogen oxides
NSCR	non-selective catalytic reduction
OSWI	Other Small Waste Incinerator
PBP	payback period
PLC	programmable logic controller
PM	particulate matter
RDF	refuse derived fuel
ROC	Recycling Operations Center
ROI	return on investment
SCADA	Supervisory Control and Data Acquisition
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
STLC	Soluble Threshold Limit Concentration
SWP	Solid Waste Preprocessor
TCLP	Toxicity Characteristic Leaching Procedure
TTLC	Total Threshold Limit Concentration
UGR	unitized group ration
U.S.	United States
VOC	volatile organic compound
WEC	waste-to-energy conversion

ACRONYMS AND ABBREVIATIONS (continued)

WTE	waste-to-energy

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

In 2011, renewable energy accounted for just 9% of total energy consumption in the United States, and just 5% (or 0.45% overall) of that (477 trillion British thermal units [BTU]) was derived from waste.[1] Waste is abundant through the populated world, and Department of Defense (DoD) installations, both fixed and forward, are no exception. The ubiquity of waste and its chemical energy content make it a good alternative fuel choice. In Fiscal Year (FY) 2010, the DoD generated approximately 6,600 tons per day of municipal solid waste (MSW), excluding construction and demolition (C&D) waste.[2] This waste provides a potential to capture approximately 165 megawatts electrical (MW_e) of electricity and 500 megawatts thermal (MW_T) of waste heat, resulting in a net solid waste reduction to landfills of 6,300 tons per day. In this ESTCP project, Infoscitex Corporation (IST), in collaboration with MSW Power Corporation (MSW Power), evaluated the potential of a distributed waste-to-energy conversion (WEC) system to provide fixed DoD sites with a local, controllable supplemental energy source. The Green Energy Machine (GEM) WEC system, developed by IST and productized by MSW Power, was demonstrated at Edwards Air Force Base (AFB) in California. The demonstration plan was devised with a number of specific quantitative and qualitative performance objectives in mind. These, along with results, are summarized in Table 1.

Table 1. Demonstration objectives and results.

Performance Objective	Success Criteria	Result
Quantitative		
Reduce amount of solid waste requiring disposal	<10% by weight of solid waste processed by GEM WEC disposed of in landfill.	**Success.** ~10% (mass basis) of the waste processed by the GEM required landfill disposal.
Generate net electricity for on site use	>7% net electricity generated per energy contained in solid waste.	**Success.** ~23% net electricity generated per energy contained in the solid waste.
	>36 kilowatts electrical (kW_e)*	**Success**. ~40 kW_e net electric output.
Power quality	Match quality typical of local utility.	**Mixed Result**. Due to issues with the local utility provider, an interconnection agreement was not executed. A full set of data was therefore not achievable. Data collected was favorable.
Generate net waste heat for on site use	>22% energy of recoverable waste heat per energy contained in solid waste	**N/A.** Because host site determined waste heat capture was not of interest, and in the interest of moving the demonstration forward, this objective was not pursued.
	>120 kilowatts thermal (kW_T)* based on a feed moisture content of 30%.	
Reduce carbon footprint	>45% reduction in total installation carbon footprint compared with landfill of solid waste.	**Success.** 101% reduction in total carbon footprint was calculated.
	> 520 metric tons greenhouse gas (GHG)/year	**Deficient**. 200 metric ton GHG/year (full capacity operation) reduction.

Table 1. Demonstration objectives and results (continued).

Performance Objective	Success Criteria	Result
Conform to ambient air quality for State of California	Not to exceed California Air Resource Board (CARB) off-road large spark ignition (>19 kW_e), > 1 liter emission standards for hydrocarbon (HC) + nitrogen oxides (NO_x) and carbon monoxide (CO).	**Deficient with Caveat.** Air emission testing revealed acceptable levels of particulate matter (PM) and CO. However, the system failed for non-methane hydrocarbon (NMHC)+NO_X. This was due to load balancing issues with load bank.
Estimate simple payback period	Less than 5 years payback period for 3 tons/day system.	**Deficient**. For the demo site, the GEM does not represent an attractive return on investment.
System robustness	>7 out of 8 hours per day for 8/5 operation and >22 hours per day for 24/7 operation; no more than 8 hours per month maintenance time.	**Deficient with Caveat.** Mixed results in meeting operating time per test segment.
Qualitative		
Ease of use	One field technician level of effort (LOE) able to routinely operate GEM WEC control system with minimal supervision.	**Success with Caveat.** System operation required a single operator. Note: logistics of site waste disposal program required a person to address hazards. No material breakdown was required before entering the system.
Automatic control system	Control system able to remotely monitor, operate and provide on-line data collection of GEM WEC system.	**Success.** Remote operation and data collection demonstrated.
Identify single point system failures	Estimates of downtimes and capital equipment replacement costs.	**Mixed Result**. Single point failures were observed, but were determined to be feedstock specific. Mitigation strategies have been identified and implemented in subsequent production of the GEM.

TECHNOLOGY DESCRIPTION

The GEM system is an integrated, stand-alone, 3 ton-per-day throughput system consisting of three major modular components:

- **Waste Handling.** A versatile solid waste preprocessing unit capable of converting a range of waste streams (refuse derived fuel and biomass, such as wood), into waste-based fuel pellets of ideal size, density, and moisture content for gasification.
- **Gasifier.** A clean-burning gasification unit capable of generating a low tar, low particulate producer gas of composition suited to produce on-site electricity from an electrical generator.
- **Electrical Generator.** An electric generator, originally designed for operating with diesel fuel, was modified to accept producer gas from the GEM gasifier. The modified genset is capable of providing a maximum gross output of 64 kW_e, with a net output of 36 kW_e (GEM requires 28 kW_e).

As shown in Figure 1, the GEM was installed by the Edwards AFB landfill and recycling center. While selecting this site seemed intuitive from a logistics and workflow perspective, the physical siting at this location presented some unforeseen hurdles due to permitting. Indeed, operating within California offered unique challenges, and the project experienced significant delays. The primary contributors to project delays were a state permitting process lacking transparency (including serial introduction of stakeholders and permitting) and a local utility provider that was slow to respond.

Figure 1. GEM waste-to-energy conversion system installed at Edwards AFB.

DEMONSTRATION RESULTS

Despite the permitting hurdles, the demonstration was completed, with a start date approximately one year after planned completion. The system operated for a total of 468 hours with a primary objective of demonstrating the ability of the GEM WEC system to convert MSW generated at a fixed DoD installation into useful energy. Waste composition played a large role in system performance during the demonstration period. A summary of demonstration operating history is provided in Table 2.

Table 2. Operating history of GEM demonstration at Edwards AFB.

Performance Metric	Target Value	Achieved Value
Total GEM Operation (hours)	592	468
Total Waste Processed (tons)	74	16.9
Average Waste Processed (pounds/hour)	250	72
Max Waste Processed (pounds/hour)	250	293.95
Max Average Ash Output (% of average waste processed)	10%	9.97%
Total $kWh_{(e)}$ Produced	25,974	13,689
Peak $kW_{(e)}$ Produced	64	62
Net Peak $kW_{(e)}$ Produced	36	40
Total kW_T Recovered	0	0
Specific Power Yield (kWh/ton)	376	810
Energy Content of Waste (BTU/pound [kWh/pound]) Average High Low	 n/a n/a n/a	 7331 [2.15] 8399 [2.46] 5804 [1.70]
Gross Electrical Conversion Efficiency [net after parasitic use]		18.8% [12.2%]

Kilowatt hour = kWh

IMPLEMENTATION ISSUES

Implementation of the demonstration effort was a more significant challenge than had been anticipated at the outset of the project. The following regulatory approvals were required to operate the demonstration at Edwards AFB:

1. License to Operate at Edwards AFB
2. Experimental Exemption from Eastern Kern Air Pollution Control District (EKAPCD)
3. Generating Facility Interconnection Agreement with Southern California Edison (SCE)
4. Permit Exemption from the Environmental Health Division of CalRecycle

Acquiring a license to operate at Edwards AFB was a relatively straightforward activity. This required IST to submit a request to Edwards AFB with background on the project and basis for request. IST received the license (AFMC-ED-3-10-006) once a town hall meeting was held at the base and no objections were heard.

Initially, it was determined that the only regulatory approval that would be required was an experimental exemption from the local authority (EKAPCD). This was received upon completion of an application and discussion with representatives from EKAPCD (designation number 110114). While this took more time than anticipated, its receipt in March 2011 imposed only a minor delay on the project.

In order to connect the GEM system to the local grid, an interconnection agreement issued by the local utility provider was required. Substantial and unexpected delays occurred due to the obstructive and unresponsive nature of the utility provider. As a result, the interconnection agreement process was abandoned, and a load bank was installed to receive electricity generated from the GEM system.

Concurrent with the pursuit of interconnection approval, IST continued to acquire the necessary accommodations at the site to ensure a successful operation. During the course of conversations and approval requests for various elements of the project, publicity for the project heightened. As a result, new stakeholders intervened requesting further review of IST’s permitting status. Corresponding conversations brought into question whether the project would represent a violation of Edwards AFB’s landfill permitting because the GEM WEC system would be located at the landfill; thus, representing a material change in use scenario from what was described in the initial permit. This revelation resulted in further delays and at one point put the project at risk of being shut down due to an initial ruling by CalRecycle that the project was not in the best interest of the public. However, IST lobbied with CalRecycle, and ultimately Edwards AFB received a Project Permit Exemption from the Kern County Environmental Health Division of CalRecycle on March 19, 2012.

Key takeaways from the non-technical aspects of demonstration preparation are:

- *New technologies may not be addressed in regulations and local ordinances.* Projects aimed at evaluating the merits of new technologies should anticipate that a significant amount of effort will be required to educate a broad base of stakeholders.

- *Publicity is not always your friend.* While being funded to demonstrate a new solution in a high visibility setting is exciting, resist the urge to tell the world. During the course of this demonstration project, publicity encumbered permitting processes and contributed to delays.
- *Demonstration siting is key.* This demonstration was sited at the Edwards AFB landfill. Placing the system physically in the path of the waste flow seemed logistically ideal. However, this site selection prolonged the permitting process, as it required Edwards AFB to appeal for an approval of landfill use.
- *Afford ample time for permitting.* As proposed, IST anticipated that permitting would be achieved concurrently with system fabrication, and that there would be sufficient time to execute the demonstration within the original period of performance. However, the permitting scenario was far more complex than originally anticipated.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Federal Government consumed 1.1% of the total energy in the United States (U.S.) in 2011.[1] The Department of Defense (DoD) is the Nation's single largest energy consumer, using 0.8% of the total U.S. energy demand and 78% of the Federal energy demand. In 2011, DoD spent $19.3 billion to sustain operations and facilities.[3] Facility energy costs accounted for ~21% ($4.1 billion). DoD has made great progress in reducing its energy consumption for buildings and meeting the President's Fiscal Year (FY) 2015 goal of 30% reduction from the FY 2003 baseline.[4] In FY 2011, military installations reduced consumption by 13.3% from a 2003 baseline, underperforming the goal of 18% reduction.[3]

The energy strategy of DoD for fixed installations consists of eliminating energy waste in existing facilities, increasing energy efficiency in new construction and renovations, and reducing its dependence on fossil fuels by incorporating renewable sources of energy. The current program involves the use of municipal solid waste (MSW) generated on the fixed installations as an alternative energy source to generate electricity and heat through high temperature gasification of MSW. The use of MSW provides a way, not only to reduce waste and environmental hazards, but to create energy that can be used in a power grid. Fixed DoD installations in the U.S. and abroad, particularly in Europe, are coming under increasing regulatory pressure to reduce the quantity of waste that goes to on-site and off-site landfills. DoD has set an objective of reducing (diverting) non-hazardous solid waste, without construction and demolition waste, by 40% by 2010[4, 5], however, states and local municipalities may have more rigid requirements. For example, California has an annual 50% waste diversion requirement.[6]

The proposed technology involves the processing of refuse derived fuel (RDF) (combustible MSW) and biomass into fuel pellets, which are combusted in a downdraft gasifier, producing a syngas (producer gas) that provides the fuel for electricity and/or heat generation while reducing the amount of waste sent to the landfill by more than 90%.

Present methods for reducing the MSW produced by Americans (which accounted for ~250 million tons in 2010) going to landfills primarily involves recovery of 34.1% of the MSW for recycling and composting; ~12% consumed by combustion with energy recovery, with the remaining ~54% disposed of in landfills.[7] Incineration (burning) with and without energy recovery, produces unacceptable air and solid waste (ash) emissions. Gasification converts carbonaceous materials to producer gas by reacting the material at high temperatures (>700EC) with a limited amount of oxygen. This process is more efficient than incineration in that more of the energy contained in the producer gas is extracted from the solid waste. For example, gasification produces 750-850 kilowatt (electrical) (kW_e) hour/ton waste compared to incineration with electricity generation, which produces 500-600 kW_e hour/ton waste. Gasification produces less air and solid waste emissions. Downdraft gasification, in which the air flows concurrently with the MSW fuel, generates less tar in the producer gas allowing for its direct integration with a generator, without installing a process for tar removal. Gasification of the fuel pellets is also more efficient than gasification of unconsolidated solid waste.

The amount of electricity and heat produced by the gasification of solid waste generated at fixed DoD installations, as well as cost savings, is substantial. The number of fixed DoD installations in the U.S. and abroad generating 3 tons per day or more of solid waste is approximately 330 installations, based on a solid waste generation rate of 4.5 pounds of solid waste per person per day[10]; the total amount of solid waste generated by both military and civilian base employees was estimated to be 6600 tons per day. At these installations, the waste-to-energy conversion (WEC) gasification system is capable of generating about 165 megawatt (electrical) (MW_e) of electricity and 500 megawatt (thermal) (MW_T) of waste heat, resulting in a net solid waste reduction to landfills of 6300 tons per day.

1.2 OBJECTIVE OF THE DEMONSTRATION

The primary objective of this program was to demonstrate and validate a WEC system capable of economically converting 3 tons per day of combustible MSW (refuse-derived fuel) on fixed DoD installations for use in a downdraft gasifier producing a syngas (producer gas) and providing fuel for electricity and heat for on site base usage. Specific objectives of the demonstration included:

- ***Reduce amount of solid waste requiring disposal***. Success criteria: ≤10% by weight of solid waste processed by system disposed of in landfill.
- ***Generate net electricity for on-site use.*** Success criteria: >7%, and not less than 36 kWe, net electricity generated per energy contained in solid waste.
- ***Power quality***. Success criteria: match quality typical of local utility.
- ***Generate net waste heat for on-site use.*** Success criteria: >22%, and not less than 120 kilowatts (thermal) (kW_T) for waste stream comprised of 30% moisture, output of recoverable waste heat per energy contained in solid waste.
- ***Reduce carbon footprint.*** Success criteria: >45% reduction in total installation carbon footprint as compared with landfill of solid waste.
- ***Conform to ambient air quality for State of California.*** Success criteria: not to exceed California Air Resource Board (CARB) off-road large spark ignition emission standards for hydrocarbon (HC) + nitrogen oxides (NO_X) and carbon monoxide (CO).
- ***Estimate simple payback period.*** Success criteria: Less than 5 years payback period for 3 tons per day system.
- ***System robustness.*** Success criteria: >7 out of 8 hours per day for 8/5 operation and >22 hours per day for 24/7 operation; no more than 8 hours per month maintenance time.
- ***Ease of use.*** Success criteria: One field technician level of effort (LOE) able to routinely operate control system with minimal supervision.
- ***Automatic control system.*** Success criteria: Control system able to remotely monitor, operate, and provide on-line data collection.
- ***Identify single point system failures.*** Success criteria: Estimate downtimes and capital equipment replacement costs.

1.3 REGULATORY DRIVERS

The primary driver for reducing energy demand on DoD installations is the President's Executive Order 13423 of January 24, 2007 to the heads of each Federal agency "to strengthen the environmental, energy and transportation management of Federal agencies" and "to improve the energy efficiency and reduce greenhouse gas (GHG) emissions through reduction of energy intensity by: (1) 3% annually through the end of FY 2015, or (2) 30% by the end of FY 2015 relative to the baseline of the agency's energy use in FY 2003."[4]

This goal of energy reduction is also made more urgent by the ever-increasing number of electronic weapon systems being developed by DoD to improve operational efficiency at fixed and tactical installations. At fixed installations, extensive computer systems, dependent on obtaining electricity from a commercial power grid, are used to support these weapon systems. The vulnerability of the power grid to physical and cyber attack and extreme weather threaten the ability to accomplish critical missions in a timely manner. Effective utilization of alternative energy sources, such as MSW in an energy conversion system, is one of several methods to provide an identifiable, available and reliable energy supply.[3]

The Air Force recently issued their Energy Plan, which serves as the operational framework for all military and civilian Air Force personnel in communicating the Air Force energy goals, objectives and metrics.[8] The Energy Plan is built upon three pillars that guide energy management within the Air Force: Reduce Demand, Increase Supply, and Culture Change. The need for a new gasifier technology falls under the Increase Supply pillar, in which the "Air Force is committed to increasing the amount of energy supplies available to enhance our nation's energy security. The Air Force will develop and utilize renewable and alternative energy to reduce GHG emissions. The goals and objectives to increase supply target these three areas: aviation fuel, ground fuels and ***installation energy***."

Executive Order 13423 also requires that all facilities "increase diversion of solid waste as appropriate and maintain effective waste prevention and recycling programs."[4] The DoD has implemented integrated solid waste management programs to achieve specific solid waste diversion goals of diverting non-hazardous waste without construction and demolition waste of 40%; the goal for construction and demolition waste is 50% by 2010.[5] Many states are also requiring waste diversion, in many cases greater than the DoD. For example, the State of California, through their Integrated Waste Management Act of 1989[6], require a diversion of 50% of all solid waste by January 1, 2000. In 2006, the California statewide diversion rate was 54%. In 2008, the solid waste diversion rates for San Francisco, California (CA), Long Beach (CA), New York (NY), Los Angeles (CA), San Jose (CA), Fresno (CA), and Portland, Oregon (OR) were greater than 60%.[9] In addition to requiring solid waste diversion, the State of California has targeted landfills as being sources of GHGs.[6] Diversion of solid waste from landfills, through solid waste prevention methods, recycling programs, or the use of WEC systems to reduce the solid waste being landfilled, will reduce the landfill GHG impact on the environment.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Infoscitex (IST) developed the Green Energy Machine (GEM) WEC system for the thermal conversion of combustible MSW (paper, cardboard, plastic, wood, and food) into electricity and heat, thereby reducing the costs associated with the generation of energy and landfill. The system utilizes downdraft gasification (not incineration) technology to convert waste into distributed and clean energy. The system readily integrates into processing streams for the military, institutions and businesses and provides a highly efficient and environmentally friendly means to derive more value from refuse.

The GEM system is an integrated, stand-alone system consisting of three major modular components: (1) solid waste preprocessor (SWP), (2) thermal downdraft gasification reactor, and (3) power generation. When integrated, the GEM system provides a turnkey, alternative energy source that requires no segregation of food waste and has the ability to supplement the energy needs of fixed military and commercial installations. A typical mass and energy diagram for the GEM is provided in Figure 2.

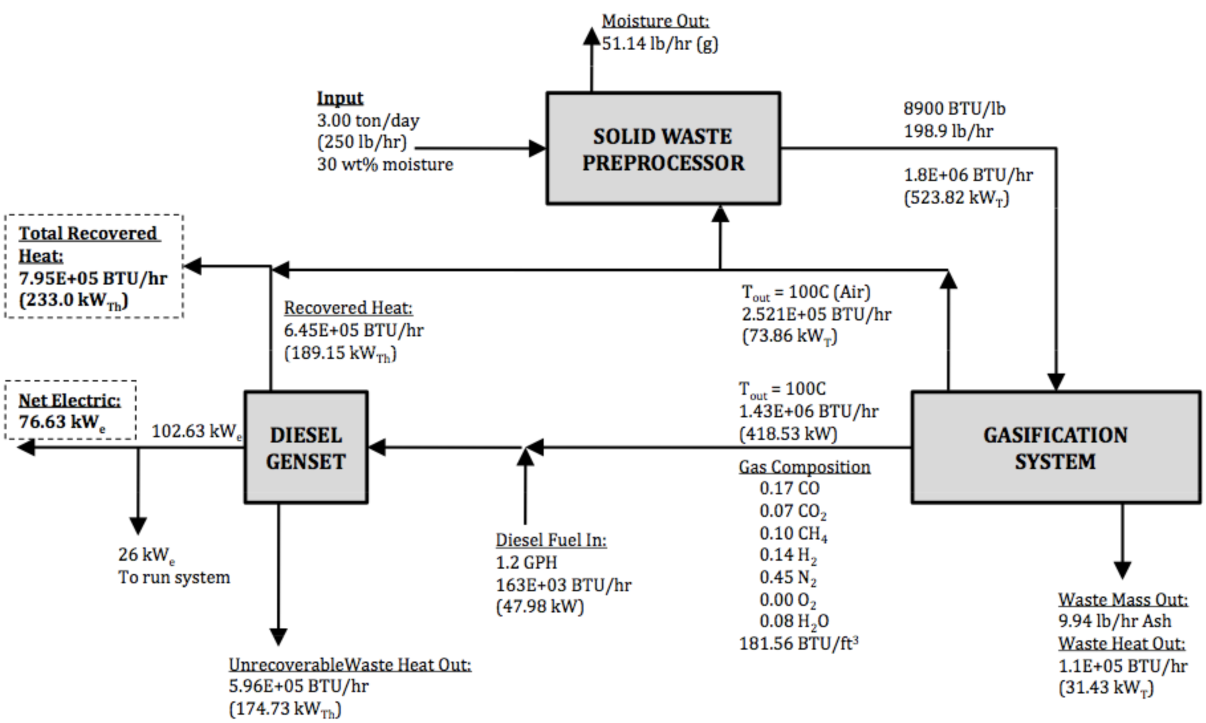

Figure 2. Typical mass and energy balance for the GEM.

The WEC system can be designed to separate the preprocessing system from the gasifier and electrical generator. The preprocessing system can be placed at the landfill site, while the gasifier and generator can be situated near the electrical grid. For the ESTCP demonstration, all of the components of the GEM system were co-located and integrated.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Downdraft gasification has a simple and stable design, generating producer gas from solid waste at a high thermal efficiency (>80%). Gasification converts carbonaceous waste materials into CO and hydrogen (producer gas) by reaction with a controlled amount of oxygen. Producer gas provides clean combustion heat, engine shaft power and electricity from a wide variety of biomass fuels. Modular units can generate up to 1 MW_e, of electrical output or up to 2.4 MW_T of thermal load. One of the primary advantages of the GEM WEC system is its ability to efficiently treat low flow rates of solid waste. The system affects large volume reductions (>95%) of the solid wastes. Gasification takes place at temperatures above 700-800EC, producing minimal pollution. A SWP system is required to densify the waste into pellets, producing a feedstock that is more amenable to gasification than unconsolidated waste. The GEM WEC system can be designed to separate the preprocessing system from the gasifier and electrical generator. The preprocessing system can be placed at the landfill site, while the gasifier and generator can be situated near the electrical grid. The disadvantages of the GEM WEC system are:

- The necessity to remove metals and glass prior to pelletization to reduce pelletizer maintenance time and system downtime.
- Low efficiency in converting the producer gas to electricity via an engine/generator.
- Additional costs are required to pelletize the solid waste.
- Electrical energy and waste heat are required to power the SWP system, reducing the total energy available for on site use.

An alternative WEC process is pyrolysis, in which the carbonaceous waste materials are broken down under pressure, and in the absence of oxygen. The process works best when the waste is carbon-rich and is a single component stream, such as wood, plastics and sewage sludge. The treatment of MSW requires extensive pre-sorting to remove the majority of non-organics and processed to homogenize the feedstock. Gasification operates at a higher temperature than pyrolysis. Pyrolysis has the potential to produce more fuels and liquids, than gases.

3.0 PERFORMANCE OBJECTIVES

Table 3 lists the quantitative and qualitative performance objectives of the Demonstration program.

Table 3. Performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Result	Rating
Quantitative Performance Objectives					
Reduce amount of solid waste requiring disposal	Tons/day of solid, non-hazardous, non-construction, waste sent to landfill	Disposal data and ash content of solid waste	<10% by weight of solid waste processed by GEM WEC disposed of in landfill.	**Success.** ~10% (mass basis) of the waste processed by the GEM required landfill disposal.	GREEN
Generate net electricity for on site use	Efficiency of energy production process to produce electricity	Metering data for net electricity produced and energy of solid waste processed by gasifier (kW_T)	>7% net electricity generated per energy contained in solid waste.	**Success.** ~23% net electricity generated per energy contained in the solid waste.	GREEN
			>36 kW_e*.	**Success**. ~40 kW_e net electric output.	
Power quality	Variations in voltage, frequency, flicker, harmonics, power factor and direct current injection	Monitoring data for AC power supplied to site and AC power generated by GEM WEC	Match quality typical of local utility.	**Mixed Result**. Due to issues with the local utility provider, an interconnection agreement was not executed. Therefore, a full set of data was not achievable. Data collected was favorable.	YELLOW
Generate net waste heat for on site use	Efficiency of energy production process to produce usable waste heat	Energy content of recoverable waste heat and energy of solid waste processed by gasifier (kW_T)	>22% energy of recoverable waste heat per energy contained in solid waste	**N/A.** Because host site determined waste heat capture was not of interest, and in the interest of moving the demonstration forward, this objective was not pursued.	BLACK
			>120 kW_T* based on a feed moisture content of 30%.		
Reduce carbon footprint	Life-cycle reduction in installation carbon footprint	Inventory of carbon emissions and sequestrations	>45% reduction in total installation carbon footprint compared with landfill of solid waste.	**Success.** 101% reduction in total carbon footprint was calculated.	YELLOW
			> 520 metric tons GHG/year**)	**Deficient**. 200 metric ton GHG/year (full capacity operation) reduction.	

AC = alternating current

Table 3. Performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Result	Rating
Conform to ambient air quality for State of California	Concentration of gas contaminants in generator emissions	Third party/IST gas emission monitoring data	Not to exceed CARB off-road large spark ignition (>19 kW_e), >1 liter) emission standards for HC + NO_x and CO.	**Deficient with Caveat.** Air emission testing revealed acceptable levels of PM and CO. However, the system failed for NMHC+NO_x. This was due to load balancing issues with load bank.	**YELLOW**
Estimate simple payback period	Ratio of system cost to annual energy and landfill savings	Net electricity and waste heat generated, reduction in solid waste to landfill, unit cost of energy, landfill disposal costs, and system cost	Less than 5 years payback period for 3 tons/day system.	**Deficient**. For the demo site, the GEM does not represent an attractive return on investment.	**RED**
System robustness	Time in hours for system operation and maintenance	Logs of system operation and maintenance	>7 out of 8 hours per day for 8/5 operation and >22 hours per day for 24/7 operation; no more than 8 hours per month maintenance time.	**Deficient with Caveat.** Mixed results in meeting operating time per test segment.	**YELLOW**
Qualitative Performance Objectives					
Ease of use	Ability of a technician-level individual to operate GEM WEC system†	Feedback from the technician on usability of the technology and time required to use	One field technician LOE able to routinely operate GEM WEC control system with minimal supervision.	**Success with Caveat.** System operation required a single operator. Note: logistics of site waste disposal program required a person to address hazards. No material breakdown was required before entering the system.	**GREEN**
Automatic control system	Remote process control and data collection of GEM WEC system	Logs of operating and performance data	Control system able to remotely monitor, operate and provide on-line data collection of GEM WEC system.	**Success.** Remote operation and data collection demonstrated.	**GREEN**

PM = particulate matter
NMHC = non-methane hydrocarbon

Table 3. Performance objectives (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Result	Rating
Identify single point system failures	Consequences and probability of single point system failures on system robustness	Listing of critical replacement components having most impact on system downtimes and equipment replacement costs	Estimates of downtimes and capital equipment replacement costs.	**Mixed Result**. Single point failures were observed, but were determined to be feedstock specific. Mitigation strategies have been identified and implemented in subsequent production of the GEM.	**YELLOW**

* Based on 520 kW_T energy contained in solid waste pellets
** GHG – based on 3 tons/day or 1095 tons/year solid waste.
† Does not include personnel for collection and conveyance of waste to GEM WEC system

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4.0 SITE DESCRIPTION

Edwards Air Force Base (AFB) volunteered to serve as a host site for the demonstration program. This site provided conditions anticipated to be typical to those found on other DoD sites. The solid waste, exclusive of construction and demolition waste, is generated by both DoD and civilian employees and is generally typical of DoD installations throughout the United States. All DoD installations have extensive paper, plastic and metal recycling operations. The Edwards AFB solid waste that goes to the landfill consists of waste generated from on-site living facilities, as well as from industrial facilities on the base. The waste from the on-site living facilities is similar to waste collected from municipalities with extensive recycling operations.

The Edwards AFB active landfill is rapidly reaching full capacity, and strict regulatory requirements make expansion prohibitively costly and time consuming. A vertical expansion of the landfill is currently being sought, but any additional capacity gained from the expansion, without strict management and budgeting of overall volume, will quickly be filled. WEC projects are desirable in that they preserve valuable landfill space through waste diversion, and they provide a source of significant cost savings through on site power and heat generation from a readily available, no cost feedstock. Edwards AFB also anticipated that the GEM WEC system could be used to treat solid waste already land filled to reduce the costs of maintaining and operating the landfill. In addition, active landfills in California and in other states are being targeted as sources of GHGs, and any diversion of waste from these landfills will help reduce the GHG impact of the landfill upon the natural environment.

Prior to processing the solid waste for disposal into landfills, the solid waste is dumped on the tipping floor and hazardous waste and aerosol cans are removed for disposal into restricted areas; metals and glass items are removed for recycling. The resulting solid waste is baled for disposal into the base landfill. With the installation of the GEM WEC system, the solid waste will be converted to energy and only 5% of the solid waste will be disposed of in the on-base landfill. Removal of metals and glass prior to conveyance to the GEM WEC system or during solid waste processing will be required at DoD installations to minimize system breakdown.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Edwards AFB, one of the largest U.S. Air Force airbases in the U.S., is located approximately 100 miles northeast of Los Angeles, California in the Mojave Desert, and encompasses 301,000 acres (121,805 hectares).[13] Most of Edwards AFB is in Kern County, with small portions in San Bernardino and Los Angeles counties. Day-to-day operations at the landfill are the responsibility of the Air Force Flight Test Center (AFTCC) 95th Air Base Wing (ABW) and the Civil Engineering (CE) Directorate (95 ABW/CE) [225 N. Rosamond Boulevard, Building 3500, Edwards AFB, CA, 93524, (661)-277-2910]. The Environmental Management Division (95 ABW/CEV) [5 East Popson Avenue, Building 2650A, Edwards AFB, CA, 93524, (661) 277-1401] is responsible for regulatory aspects of the landfill. The landfill is located in the Kern County portion of Edwards AFB. The facility has no formal street address.

4.2 FACILITY/SITE CONDITIONS

The demonstration was held at the existing landfill facility between the baler building (Building 7996) and the Recycling Operations Center (ROC) (Building 7998) shown in Figure 3.[10] Waste is disposed of at the landfill using two methods: above-grade balefill and area fill. Several active faces are present to provide operational flexibility with balefill, area fill, or combined methods of disposal. A ROC and composting facility are also operated at the landfill. The majority of residential and commercial waste is collected by commercial haulers. Access is provided to base personnel/residents in privately owned vehicles. Construction and demolition waste (CDW) is trucked to the landfill by private construction contractors working on the base. The landfill is accessed via a driveway on Landfill Road. Daily trash generation is approximately 18 to 30 tons/day. The landfill is operated 5 days during the week from 6:30 AM to 4:30 PM and on Saturday from 7:30 AM to 10:30 AM. Trash is not generated on the weekends.

Figure 3. Location of demonstration site.

Recycling is currently conducted on base at the ROC. The ROC is located on the south boundary of the landfill, east of the main entry gate, adjacent to and east of the baler building (Figure 3). Recyclable materials are delivered to the ROC from a residential curbside collection program, an industrial area collection program, individual drop-offs by base personnel in privately owned vehicles, and a landfill screening program. Materials are sorted at the ROC using a combination of mechanical and manual separation techniques.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

For the purposes of the assessment of the demonstration, the GEM was viewed as the independent variable (although, truly, its performance was dependent upon the waste stream it processes). Specifically, the key outcome of the demonstration was dependent upon the performance of the GEM. As a result of the demonstration, relationships between the implementation of the GEM and key macro parameters were drawn (i.e., those described in the Performance Objectives). The basis for funding this effort was that the GEM would have a marked positive impact on operations as measured by the performance objectives. The expectation was, therefore, that this would be proven out as a result of the demonstration.

Demonstration and evaluation of the GEM WEC system had five operational phases:

1. Ship/Installation;
2. Initial Start-up, Commissioning and Training of Edwards AFB Staff;
3. Five-Day Weekly (5 days x 8 hour) Operation;
4. Six-Day Weekly (6 days x 24 hour) Operation; and
5. Shutdown and Transfer of Ownership of GEM WEC to Edwards AFB.

The operational phases were designed to evaluate the system from the initial startup, through daily operation, and culminating in the complete shutdown and transfer ownership of the unit to Edwards AFB. Test data, obtained during each operational phase of the demonstration at Edwards AFB, was used to evaluate the performance objectives of the GEM WEC system. Data sampling points were used for characterizing the individual performance of the SWP and thermal decomposition/energy generation subassemblies, as well as the overall performance of the GEM WEC system. Cost data was also obtained to estimate realistic life cycle costs of the GEM WEC system. All of the components of the GEM WEC system were controlled by programmable logic controllers (PLCs). A Supervisory Control and Data Acquisition (SCADA) system monitored the entire GEM WEC system and allowed the system operator to change the set points of specific PLCs for individual events, monitor operating conditions, and analyze performance information. Specific details of each major component of the GEM WEC system and the experimental design are provided in the following sections.

5.2 BASELINE CHARACTERIZATION

Experimental trials were run with simulated solid waste consisting of meals-ready-to-eat (MREs) and paper and cardboard to obtain energy usage data and shredded/pelletized waste characteristics (Table 4). Ultimate and proximate analyses of the pellets were carried out by an independent testing laboratory (Table 5). This composition was based on the Force Provider Fort Polk characterization study without the metal and glass content.[9]

Table 4. Composition of simulated waste streams based on Force Provider Fort Polk characterization study.[9]

Component	Mass (pounds)	Weight%	Source
Food	210	44.5	MRE food waste
Paper	199.5	42.2	MRE fiberboard cases, MRE packaging, Chinette trays, cardboard
Plastic	63	13.3	MRE packaging, UGR plastic trays, bag liners

UGR = unitized group ration

Table 5. Ultimate, proximate, and heating value analyses of waste pellets.

Analysis	IST Pellets	
	Air Dried	Dry
Proximate		
Moisture, percent	5.3	0
Ash, percent	5.81	6.14
Volatile, percent	77.3	81.63
Fixed carbon, percent	11.59	12.23
Ultimate		
Carbon, percent	49.82	52.61
Hydrogen, percent	6.94	7.33
Nitrogen, percent	0.85	0.90
Sulfur, percent	0.15	0.16
Oxygen, percent	31.13	32.86
Heating Value		
Higher Heating Value, BTU/pound (kJ/kg)	9178 (21,334)	9692 (22,528)
Lower Heating Value, BTU/pound (kJ/kg)		9004 (20,929)

BTU = British thermal unit
kJ/kg = kilojoule/kilogram

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

5.3.1 Overall System Description

The GEM WEC system consists of preprocessing sub-assembly, thermal decomposition/energy generation sub-assembly, and two control cabinets. For the demonstration, the system was shipped to Edwards AFB in an 8'6" wide x 9'6" tall x 40' long (2.6 m x 2.9 m x 12.2 m) International Organization for Standardization (ISO) container. One side of the ISO shipping container was placed against the ROC building at Edwards AFB. Power output from the generator was tested using a load bank. Waste heat from the GEM WEC system was either used to dry the shred or exhausted to the atmosphere.

5.3.2 GEM WEC Control System

A SCADA system monitored the entire GEM WEC system. Most control actions were performed automatically by PLCs and not by the SCADA system.

5.3.3 Solid Waste Feed

Solid waste was hauled to the baler building, dumped on the tipping floor, and back-dragged with a loader into a thin layer, and then was inspected for hazardous waste and other prohibited items. A front end loader transported the waste from the baler building to the GEM WEC unit, where it lifted the self-dump hopper above the dump hopper on top of the ISO container. The fork lift operator remotely opened and rotated the self-dump hopper and unloaded the solid waste into the ISO dump hopper.

5.3.4 Gasification Reactor

The gasifier is a thermal reactor designed to convert the solid densified material (pellets) into a gas containing the constituent gaseous elements found in the pellets. The gasifier used in the GEM WEC system is a downdraft gasifier in which both the solid fuel particles (pellets) and air move in the same direction down through the reactor vessel. The solid fuel is fed through the top of the gasifier into the waste/air inlet zone. The pellet flow through the reactor vessel is controlled by the grate drive. Air is drawn through the fuel pellets and the producer gas cleanup system by using the suction of the engine. Fuel pellets pass into the pyrolysis zone from this stage. It is within the pyrolysis or devolatilization stage that initial conversion begins and char is produced.

5.3.5 Power Generation

Producer Gas Analysis
TRC Companies, Inc. performed the producer gas analysis due to issues with IST's equipment. The producer gas was collected using a tedlar bag after the reactor blower. The sample was then analyzed via gas chromatography pursuant to American Society for Testing and Materials (ASTM) D 1945-96 2003. Table 6 summarizes the data.

Table 6. Producer gas analysis.

Fuel Value (%), Moisture & Ash Free					GCV	
Carbon	**HC**	**Nitrogen**	**Oxygen**	**Sulfur**	**Btu/pound, dry**	**BTU/ft^3**
13.96	2.22	62.17	21.65	0	2,174.60	167.9

GVC = gross caloric value

Engine/Electric Generator
Producer gas provides shaft engine power/electricity generation for small systems, primarily for shaft power generation (to 200 kW_e).[10] Downdraft gasifiers have a rapid response time so they are suitable for powering engines with either varying or fixed loads. The generator unit featured a 135 kW_e diesel engine modified to accept producer gas from the gasification process. The intake manifold was modified to allow for syngas to enter the engine as well as the fuel injection pump to limit the amount of diesel that is supplied. One of the objectives of this program was to quantitatively determine if the power quality or quality of the voltage, frequency and harmonics of the electricity generated by the GEM WEC system matched the power quality of the AC power for the site without significant loss of performance or life. Electricity generated by the

GEM WEC system was supplied to a load bank due to unresponsiveness on the part of the local utility provider (an interconnection approval is required for grid safety purposes). A switch gear was utilized to prove that paralleling to the grid characteristics is achievable.

5.4 OPERATIONAL TESTING

The operational testing schedule involved installation, startup/commissioning, multiple 8x5 tests, and two 24x6 tests. The 8x5 testing was performed over the course of several weeks and included operating 8 hours per day for a 5 day period. The 24x6 testing was performed twice and included operating for 6 days straight in a simulated three work shifts per day fashion. Table 7 summarizes key achievements against operational metrics. The GEM was packaged and ready for delivery to Edwards AFB on April 19, 2012. The GEM container, diesel generator container, and auxiliary equipment was loaded onto two flatbed trucks and shipped to California. The GEM arrived at the landfill site within Edwards AFB on April 25, 2012. Installation of the GEM began on April 25, 2012. During this phase of the project, the team located and placed the GEM on the concrete slab. Over the course of the following 3 weeks, the GEM was fully installed.

Table 7. Summary of top level performance.

Performance Metric	Target Value	Achieved Value
Total GEM Operation (hours)	592	468
Total Waste Processed (tons)	74	16.9
Average Waste Processed (pounds/hour)	250	72
Max Waste Processed (pounds/hour)	250	293.95
Max Average Ash Output (% of average waste processed)	10%	9.97%
Total $kWh_{(e)}$ Produced	25,974	13,689
Peak $kW_{(e)}$ Produced	64	62
Net Peak $kW_{(e)}$ Produced	36	40
Total kW_T Recovered	0	0
Specific Power Yield (kWh/ton)	376	810
Energy Content of Waste (BTU/pound [kWh/pound]) Average High Low	 n/a n/a n/a	 7331 [2.15] 8399 [2.46] 5804 [1.70]
Gross Electrical Conversion Efficiency [net after parasitic use]		18.8% [12.2%]

kWh = kilowatt hour

On May 11, 2012, the GEM was fully installed and ready for startup. Unfortunately, the AFB did not have its base license approved so the GEM was not operated until the license was approved. However, an initial startup checklist was performed to ensure proper installation. On June 18, 2012, the base license was approved and the GEM was ready for startup and commissioning. The first GEM operation occurred on June 20, 2012. It was during the commissioning phase where a fault in the generator was discovered. The generator used at Edwards AFB originally was not the same unit that was tested at Waltham, Massachusetts. Due to the pending Southern California Edison (SCE) application, the original manufacturer's generator was installed on the diesel engine to avoid the requirement to submit amended interconnection documentation. Through testing and analysis, it was determined that the generator had a short in its windings. Therefore, the generator needed to be replaced. Based on budget constraints and lack of movement by SCE in evaluating the interconnection application, MSW Power Corporation (MSW Power) sent its backup generator to Edwards AFB. This generator wasn't replaced until July 17, 2012.

During the generator troubleshooting and replacement period, the gasifier and SWP systems were commissioned and adjusted for the change in feedstock characteristics. The production of syngas was flared to the environment during this phase. The general operation timeframe was 8 hours per day 5 days a week. Full system 8x5 operation began on July 18, 2012. This operation continued for 4 1/2 weeks before the first 24x6 operation. The end of the first set of 8x5 operation occurred on August 10, 2012.

The first 24x6 operation occurred from August 13-19, 2012. During this time, the GEM was run continuously for 144 hours. On August 20, 2012 the second set of 8x5 operation occurred. This operation lasted until September 13, 2012. During this phase of operation, emission testing was conducted.

The final stage of operation of the unit at Edwards AFB occurred during the second 24x6 test. The operation ran from September 16-22, 2012. After the second 24x6 operation, the GEM was closed up for long term storage. On February 4, 2013, the system was disassembled and removed from the site on February 8, 2013 and delivered to Massachusetts on February 14, 2013.

5.5 SAMPLING PROTOCOL

Data was sampled and recorded for all of the working operational phases and during all of the test runs when the system was in operation. Data averages were taken over specified time intervals. Emission test data from the generator was prepared by contract third party TRC Companies, Inc.[11] Samples collected during the working operational phases for physical and chemical characterization were: the solid waste entering the shredder, the pellets entering the gasifier, and the following GEM WEC effluents (bottom ash, particulate matter and fly ash). Tars were not collected, but were analyzed in line. Every day samples were collected during the first hour of the run, middle of the run and within the last hour of the run, blended together, and prepared for analysis. The mass and energy balance is strongly dependent on the energy content of the pellets. As a result, the pellets were analyzed for their energy content daily.

5.6 SAMPLING RESULTS

5.6.1 Electrical Output

Data was collected approximately every 5 seconds. Site limitations associated with local utility provider hampered the ability to feed power to the facility. Thus, electrical output data, while demonstrative of the ability of the GEM WEC System to generate power, could not be compared to grid power characteristics.

5.6.2 Air Emissions

Sampling was performed on September 12, 2012. Testing consisted of three 60-minute test runs for compliance determination on the engine stack while the unit operated at normal production limits. Environmental Protection Agency (EPA) Method 3A (O_2/CO_2), EPA Method 6A (SO_2), EPA Method 7E (NO_x), and EPA Method 10 (CO) were performed. Triplicate 60-minute test runs were also performed for PM determination using EPA Method 1A (Sample and Velocity Traverses for Small Stacks or Ducts) and Air Resources Board (ARB) Method 5 (Particulate). HC testing consisted of triplicate 60-minute canister sampling using South Coast Air Quality Management District (SCAQMD) Method 25.3 (volatile organic compound [VOC]). Fuel sulfur content was determined utilizing EPA Method 19 (Gas Chromatography with Flame Photometric Detector [GC-FPD]). In addition to compliance testing, samples of diesel fuel (used for co-firing) and producer gas were collected and analyzed for carbon, hydrogen, oxygen, nitrogen, sulfur, heat content, and heating value in accordance with ASTM D240, ASTM D5373, ASTM D1945, and ASTM D3588. Sulfur emissions were determined from the diesel fuel sulfur and producer gas sulfur content in accordance with ASTM D3120 and ASTM D3246. As shown in Table 8, the emissions were compliant for particulate matter and CO emissions, but failed to meet regulations for NMHC+NO_x.

Table 8. Summary of emissions compliance tests.

	NMHC + NO_X (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	Gallons per Hour
Tier 3 Standard	***3.00***	***0.15***	***2.60***	---
Test 1	3.21	0.08	0.01	1.23
Test 2	4.92	0.09	0.47	0.61
Test 3	4.83	0.09	1.05	0.31
Average	4.32	0.08	0.51	---

g/bhp-hr = grams per brake horsepower-hour

5.6.3 Solid Waste Emissions

Personnel from Edwards AFB were responsible for performing analysis of ash samples collected by the GEM operator. Sampling occurred over the period of July 2012 to September 2012 and took place at the demonstration site at the Main Base Active Landfill (MBAL). Samples were analyzed for the following contaminants:

- Cam 17 metals by EPA Method 6020
- Dioxins and furans by EPA Method 8290
- California Code of Regulation (CCR) Title 22 Hazardous Waste Bioassay

Test results are summarized in Table 9. Metal contamination at unacceptable levels was found in all samples with the exception of the sample for the second day of the ninth week (August 29, 2012 sample set). All samples passed the dioxin and furan test. With the exception of the sample for the first day of the tenth week (September 17, 2012 sample set) all samples passed the Hazardous Waste Bioassay screen. The primary conclusion to be drawn from this data is that the Edwards AFB waste stream had a high representation of metals within its constituency.

Hazardous levels in the ash can be mitigated through inclusion of active metal separation in the preprocessing area of the GEM (as is provided in the current generation of the technology).

Table 9. Ash sample analysis.

Parameter	TCLP mg/L	STLC mg/L	TTLC mg/kg	Week 1 Composite mg/kg	Week 2 Composite mg/kg	Week 3 Composite mg/kg	Week 4 Composite mg/kg	Week 5 Composite mg/kg	Week 6 Composite mg/kg	Week 7 Composite mg/kg	Week 8 Composite mg/kg
Antimony		15	500	*160*	13	*250*	47	18	40	31	32
Arsenic	5.0	5.0	500	1.2	0.81	103	1.0	1.3	0.66	0.98	1.1
Barium	100	100	10000	280	190	250	170	*980*	340	380	470
Beryllium		0.775	75	0.15	0.20	0.12	0.079	0.16	0.17	0.14	0.27
Cadmium	1.0	1.0	100	*15*	0.42	***24***	8.7	4.0	4.2	*12*	***31***
Chromium	5	5(560)	2500	***240***	*77*	***110***	*60*	28	*67*	38	*46*
Cobalt		60	8000	9.6	6.3	4.7	2.2	2.6	2.2	4.6	4.0
Copper		25	2500	*7800**	*9400**	*290*	*2000*	*2800*	*1800*	*790*	*310*
Lead	5.0	5.0	1000	***110***	*53*	***170***	***160***	***100***	*78*	*75*	***210***
Mercury	0.2	0.2	20	ND	ND	ND	ND	ND	ND	ND	ND
Molybdenum		350	3500	13	7.4	9.0	7.0	2.8	4.3	5.5	7.6
Nickel		20	2000	*300*	160	*200*	86	140	130	68	72
Selenium	1.0	1.0	100	ND	ND	ND	ND	0.65	0.34	0.37	ND
Silver	5.0	5.0	500	30	4.7	11	8.9	1.7	1.6	5.9	10
Thallium		7.0	700	ND	ND	ND	ND	0.13	ND	0.13	ND
Vanadium		24	2400	3.6	11	1.4	3.8	6.8	6.4	5.4	4.5
Zinc		250	2500	*3200**	*3500**	*3000**	1200	*21000**	1300	1800	*2800**
Dioxin (2,3,7,8-TCDD)		0.001	0.01	0.000064	0.00003	0.000015	0.000088	0.00000026	0.00013	0.00046	ND
Haz Waste Bio Assay[a, b]	N/A	N/A	PASS LC50>750 mg/L	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

Notes:
Complete analytical results are presented in Appendix A
Value exceeding TCLP or STLC
Value approaching the TCLP or STLC limits
Failed Haz Waste Bio Assay
Values exceeding 20 x TCLPs are in **bold**
Values exceeding 10 x STLCs are in *italics*
Values exceeding TTLCs are indicated by asterisk*
[a] This is a pass/fail test, at 750 mg/L. the final fish survival rate is used to determine whether or not the sample passes state criteria for non-hazardous waste, namely an LC50 greater than 500 mg/L (in other words, the concentration necessary to kill half of the exposed fish must be greater than 500 mg/L).
[b] CCR Title 22 Fathead Minnow Hazardous Waste Screen Bioassay (Polisini & Miller, 1988).
mg/L = milligrams per liter
mg/kg = milligrams per kilogram
TCLP = Toxicity Characteristic Leaching Procedure
STLC = Soluble Threshold Limit Concentration
TTLC = Total Threshold Limit Concentration
Common Laboratory Data Qualifiers and their descriptions can be seen on the individual laboratory reports.

6.0 PERFORMANCE ASSESSMENT

6.1 QUANTITATIVE PERFORMANCE OBJECTIVES

6.1.1 Reduce Amount of Solid Waste Requiring Disposal

During the period of August 13-19, 2012 the gasification reactor ran for a total of 122.95 hours and processed 7939 pounds of pellets. This equates to an average throughput of 64.57 pound/hour. As a result, 794 pounds of total ash (bottom ash plus fly ash) were produced. This equates to an average ash generation rate of 6.46 pound/hour. Average input and output moisture were 10.28% and 7.63%, respectively. Based on this data, solid waste was reduced to 8.97% of its original mass after processing in the GEM WEC System. Therefore, this performance objective was met.

Solid waste feed to GEM	8849 pounds
Moisture content of feed to GEM	10.28 % (or 909.7 pounds)
Mass of ash exiting GEM	794 pounds
Percent mass reduction by GEM	**91.03%**

6.1.2 Generate Electricity for On Site Use

Data capture from the first day of a 7-day period will be used as a basis for evaluation of this objective. This day included start-up and is therefore anticipated to represent the lower end of system output for typical operations. Data collected on August 13, 2012 is contemplated here. On this date, the generator operated for 4 hours and 45 minutes, and was under a load of 44 kW from the load bank. Due to limitations at the site, data corresponding to parasitic load from the GEM was not captured. However, historical data indicates an average parasitic load of 8.67 kW for the entire process system per ton of solid waste processed. A total of 832 pounds of waste was processed by the preprocessor; therefore, a parasitic loss of 3.61 kW is assigned for this period. Net production is therefore 40.39 kW. This exceeds the threshold target of 36 kW for this performance objective.

In addition to the numerical target of 36 kW, this performance objective was also concerned with net electricity output as percentage of chemical energy in the waste feed. On August 13, 2012, the GEM operated for 11.37 hours. Pellet analysis data revealed fluctuation in the waste energy content. An average gross heating value of 8905 BTU/pound is used for the analysis based on data collected. Of the 832 pounds of waste that was fed to the preprocessor, 666 pounds in the form of pellets was processed by the gasifier during the 11.37 hour period. The average flow rate was 58.6 pounds/hour; therefore, the input energy was 520,000 BTU/hour (150 kW). The net energy generated was 23.5% of the input energy, easily exceeding the threshold of 7%.

6.1.3 Power Quality

IST Energy tracked frequency, power output, and voltage over the course of the GEM WEC demonstration. Although the switch gear was never connected to the grid, the power quality was found to be satisfactory for commercial use.

6.1.4 Generate Net Waste Heat for On-Site Use

The energy contained in the total waste heat could not be calculated. The pitot tubes installed in the waste heat line malfunctioned and therefore the velocity of the gas remains unknown. The temperature of the gas may have exceeded the permissible limits of the pitot tubes leading to their failure.

6.1.5 Reduce Carbon Footprint

The metric for this objective is the life cycle reduction in the carbon footprint as a result of the gasification of combustible solid waste compared to landfill methane generation created by the disposal of solid waste into the landfill. To perform the analysis, noncombustible portions of the waste stream were not considered, as they do not contribute to GHG emissions when landfilled nor are they converted by gasification. Table 10 summarizes typical distribution of combustible waste stream constituents. Also provided in Table 10 are emission factors as provided by Ruppert et al.[12]

Table 10. Waste composition by weight.

Component	Weight Percent	Emission Factor Landfilling ($(b_i)_l$)	Emission Factor Gasification ($(b_i)_g$)
Food	39.0	0.20	-0.04
Paper	25.0	0.53	-0.15
Plastic	23.5	0.01	0.30
Cardboard	12.5	0.11	-0.16

Based on Table 9, the percent change in GHG emissions as a result of GEM process equaled -101%. The success threshold for this aspect of the carbon footprint performance objective was a reduction of 45%; thus, the project successfully exceeded this aspect of the objective. Calculating the annual reduction in GHG emissions based on a period when 8849 pounds of waste was processed over a time span of 122.95 hours results in -56 metric tons/year. Notably, this fell short of the objective 520 metric tons per year. Contributing factors to this are:

- ***Reduced throughput.*** The system processed 28% of the design throughput due to feedstock. Operating at full capacity would increase the GHG reduction to 200 metric tons per year.
- ***Feedstock composition.*** Plastic is a negative contributor to GHG emissions from gasification. The site has higher plastic content, leading to higher impact.

6.1.6 Conform to Ambient Air Quality for State of California

TRC Companies, Inc. performed emission sampling on September 12, 2012. Three 60-minute equivalent test suites were conducted on the diesel engine model while it ran in conjunction with the generator as part of the GEM WEC system. The GEM WEC did not meet the EPA Tier 3 Emission Standards for Nonroad Diesel Engines for NMHC + NO_x, but did for PM and CO. The root cause of poor results for NMHC + NO_x is as follows:

- The load bank provided a fixed load of 28 kW and the engine was modified to accept syngas by installing a T-fitting at the air inlet.
- The flow of syngas fuel into the engine was fixed, causing the engine, which is naturally aspirated, to be unable to adjust its air to fuel ratio based on the richness of the syngas.

This is supported by the results for the average gallons per hour consumption of diesel fuel during each of the emission test trials. As shown, the higher the consumption, the greater the NMHC + NO_X emissions. Accordingly, the uncombusted components of the syngas and diesel fuel were realized downstream in the exhaust, thereby contributing to NMHC. Theoretically, if the GEM WEC was connected to the grid as originally planned, the load on the generator would change based on the quality of the syngas. Best Available Control Technologies (BACT) exist that can be used to reduce NMHC + NO_X, including installing a non-selective catalytic reduction (NSCR) system. This technology injects a calculated amount of reducing agent such as urea or ammonia into the exhaust gas stream to convert the NO_X emissions into harmless N_2.

6.1.7 Estimate Simple Payback Period

The calculation of the simple payback period (PBP) is based on fixed costs (capital equipment cost, installation accommodation costs, and training) and annual cost savings associated with electricity and heat generated by the system along with waste disposal cost avoidance. Annual cost savings are adjusted for annual recurring costs (operation, maintenance, periodic part replacement). Table 11 provides a summary of factors and associated impacts.

Table 11. Simple payback period factors.

PBP Factor	Notes/Comments	Edwards AFB Demo Data†	Edwards AFB Full Capacity‡	Edwards AFB Full Capacity‡ with Heat
Non-Recurring Up-front Costs				
GEM Purchase Price	Current commercial price from MSW Power Corporation	$1,1000,000	$1,1000,000	$1,1000,000
Installation Costs	Based on actuals for Edwards AFB only	$47,000	$47,000	$47,000
Operator Training	Estimated cost of training	$15,000	$15,000	$15,000
Subtotal – Non-Recurring Up-front Costs		**$1,162,000**	**$1,162,000**	**$1,162,000**
Annual Savings via Cost Avoidance				
Electricity Savings	Assumed $0.08/kWh retail cost	$24,175	$45,000	$45,000
Heat Savings	Assumed $0.03/kWh natural gas	$0	$0	$40,800
Waste Disposal Savings	Assumed $75/ton	$18,400	$63,900	$63,900
Subtotal – Annual Savings via Cost Avoidance		**$42,875**	**$108,900**	**$149,700**
Annual Recurring Costs				
Consumables	Based on actuals for Edwards AFB only, annualized	$13,000	$13,000	$13,000
Maintenance	Based on actuals for Edwards AFB only, annualized	$13,000	$13,000	$13,000
Subtotal – Annual Recurring Costs		**$26,000**	**$26,000**	**$26,000**
Total Annual Benefit (Cost Avoidance Less Recurring Costs)				
		$16,875	**$82,900**	**$123,700**
Simple Payback Period				
Simple PBP		69 years	14 years	9.4 years

† Representative throughput was 72 pound/hour and ash output was 6.46 pound/hour; per 6.2.2, electricity output was 40.39 kWe.
‡ Full capacity of the GEM is 250 pound/hour; parasitic loss higher due to higher throughput (8.67 kW vs. 3.61 kW)

6.1.8 System Robustness

The robustness of the GEM WEC was determined from July 18, 2012 to September 22, 2012. On July 18, 2012, the generator became fully operational. September 22, 2012 was the final day of the second 24 x 6 run. During this time, there were 16 days of unscheduled downtime of the entire GEM WEC. Table 12 provides a description of the maintenance performed.

Table 12. Maintenance performed during demonstration.

Date	Comments
7/23/2012	Built fines separator. Inspected bottom of HX. Secondary Air flowmeter installed. Inspected baghouses. Cleaned dryer filter and exhaust line. General SWP cleanup.
8/6/2012	Engine maintenance to support 24 x 6 run
8/7/2012	Engine maintenance to support 24 x 6 run
8/8/2012	Engine maintenance to support 24 x 6 run
8/10/2012	Engine maintenance to support 24 x 6 run
8/20/2012	Replaced filter bags. Cleaned heat exchanger. Emptied bottom ash and cyclone ash. Setup MKS. Inspected and cleaned shredder, dryer exhaust and dryer bed. Cleaned SWP floor.
8/21/2012	Finished putting on HX cover. Installed new engine exhaust, and vacuumed reactor side of container. Replaced TCs.
8/22/2012	Performed waste characterization of Edwards AFB waste.
8/23/2012	Picked up vice clamp for MKS repair. Removed intercooler.
8/24/2012	Cleaned intercooler with acetone. Removed old turbo and installed new one. Attempted to repair MKS.
9/10/2012	Travel day.
9/11/2012	Prepared system for emission testing. Modified exhaust for sampling ports. Changed filter bags. Loaded char. Exchanged bottom ash and cyclone ash bins. Performed general cleanup of GEM area. Received TRC emission team and oriented them to GEM to ensure successful testing.
9/13/2012	Emptied reactor. Cleaned heat exchanger. Organized ash barrels. Greased pellet mill. Emptied heavies bin. Changed dryer exhaust filter. Cleaned dryer bed.
9/14/2012	Cleaned secondary air. Inspected cyclone piping and venturi. Changed filter bags, bottom ash, and cyclone ash. General cleanup of GEM area.

HX = heat exchanger

During the first 24 x 6 run (Table 13), there were 3 days that did not meet the 22 hour per day requirement. On day #1, there was a premature shutdown to assess the poor syngas quality. In the evening on day #4 going into day #5, the system was shut down for routine maintenance. During the second 24 x 6 run (Table 14), only 2 days met the 22 hour per day requirement. On day #1, a communication cable melted and therefore the operator was unable to control the GEM WEC. On day #3, 10 1/2 hours of maintenance was performed and 6 hours and 6 minutes of maintenance was performed on day #4. On day #5, the system was offline for 17 hours and 22 minutes in order to conserve pellets while the main pellet mill shaft was being repaired.

There was only one day when the GEM WEC was run for an 8/5 operation that the system had to shut down prematurely due to a failure. On August 28, 2012, the gasifier was prematurely shutdown at 12:45 pm because the gear box on ash auger 2 malfunctioned and needed to be replaced. The reactor was only run for approximately 4 hours, which does not meet the 7-hour criteria.

Table 13. First 24x6 run.

Date	Gasifier Start Time	Gasifier Stop Time	Duration of Operation on Pellets	Comments
8/13/2012	8:29 AM and 5:16 PM	1:05 PM and N/A	9 hours 39 minutes	Day #1 of 24 x 6 testing. Forced to shut down reactor due to poor gas quality and therefore unable to run the engine. Pellet mill conditioner jam at 12:02 PM.
8/14/2012	N/A	N/A	24 hours	Day #2 of 24 x 6 testing. Buckets of char loaded on top of reactor in attempts of raising flame front of reactor. Pellet auger used manually to ensure complete burn through to top of reactor. Load bank continuously over temperature due to faulty switch on panel.
8/15/2012	N/A	N/A	24 hours	Day #3 of 24 x 6 testing. At around 2:00 AM, the load bank started to smoke; it turned off, and then refused to turn on again. The GEM was operated independently from the generator for the rest of the day.
8/16/2012	N/A	5:26 PM	17 hours 26 minutes	Day #4 of 24 x 6 testing. Reactor shutdown at 8:00 PM for maintenance. Reactor drained, bottom of heat exchanger cleaned, filter bags changed, piping from HX to filter bags cleaned, as well as piping from filter bags to blower and blower to generator valve.
8/17/2012	10:49 AM	N/A	11 hours 57 minutes	Day #5 of 24 x 6 testing
8/18/2012	N/A	N/A	24 hours	Day #6 of 24 x 6 testing
8/19/2012	N/A	7:00 AM	7 hours	Day #7 of 24 x 6 testing

Table 14. Second 24x6 run.

Date	Gasifier Start Time	Gasifier Stop Time	Duration of Operation on Pellets	Comments
9/17/2012	10:33 AM	N/A	10 hours 24 minutes	Day #1 of 24 x 6 testing. Ash auger jams at 12:30 PM , 1:23 PM, 1:41 PM. Lost Ethernet link to I/O at 5:00 PM. Re-patched five outputs to gasifier PLC I/O; system restored at 7:00 PM. Replaced melted Ethernet cable with temp fix I/O now working.
9/18/2012	N/A	N/A	24 hours	Day #2 of 24 x 6 testing. Added 100 gallons of diesel to tank.
9/19/2012	N/A and 6:37 AM	2:37 AM and 5:30 PM	13 hours 30 minutes	Day #3 of 24 x 6 testing. Communication failure with controller at 8:30 AM. Shutdown at 2:37 AM and 5:30 PM for Demos on 9/19 and 9/20, respectively.
9/20/2012	6:06 AM	N/A	17 hours 54 minutes	Day #4 of 24 x 6 testing. Shaft of pellet mill fractured. New part placed on order. Machine shop contacted to aid in new installation.
9/21/2012	8:22 PM	2:52 AM	6 hours 38 minutes	Day #5 of 24 x 6 testing. Reactor shutdown at 2:52 AM to conserve pellets and await fully operational pellet mill.
9/22/2012	N/A	11:20 PM	23 hours 40 minutes	Day #6 of 24 x 6 testing.

I/O = input/output

6.2 QUALITATIVE PERFORMANCE OBJECTIVES

6.2.1 Ease of Use

Two employees from IST Energy were involved GEM WEC operation; one to deal with solid waste inputs and another to operate the gasification unit. Involvement of the employee dealing with solid waste was necessitated by the logistics of Edwards AFB's waste management operation. No manual breakdown of waste was required to accommodate its processing by the GEM.

6.2.2 Automatic Control System

The GEM WEC system was controllable from Waltham, Massachusetts when a virtual private network connection was established with the server in Waltham.

6.2.3 Identify Single Point System Failures

A key aspect of ensuring system reliability is the identification of single point failure risks and appropriately mitigating them. As a result of the demonstration, four single point failure risks were identified:

- ***Pellet mill.*** The waste composition at Edwards AFB was determined to be higher in metal than anticipated. Bulk metal inclusions were found to reduce the reliability of the pellet mill by initiating jamming. On July 24, 2012, a jamming event led to the main pellet mill shaft severing, thereby rendering the equipment inoperable for 2 days. The replacement part cost $1,000. To avoid this type of issue in the future, new models of the GEM have been designed to include enhanced metal separation, which would divert bulk metal inclusions prior to reaching the pellet mill.
- ***Engine.*** Due to decreasing engine performance, the genset engine was inspected on August 24, 2012. The inspection revealed blade damage within the turbo, apparently due to foreign material intrusion. A new turbo charger was ordered and installed the following day with a replacement part cost of $500. The source of the foreign material was not determined; however, as no special precautions were made to protect the engine against sand, this very well may have been the cause. It is therefore recommended that future deployments of the system to desert settings consider countermeasures to reduce sand intrusion.
- ***Cyclone.*** During the decommissioning of the GEM (February 4-8, 2013) a break in one of the welds on the cyclone inlet piping was discovered. The piping was covered with insulation throughout the demonstration period, and therefore was not discovered. It is suspected that this may have contributed to the reduced output of the system during the demonstration period.
- ***Ash removal.*** During operation on August 28, 2012, the second stage ash auger gearbox malfunctioned. The part was replaced the next day at a cost of $700. Cause of the malfunction is believed to be passage of abnormally large clinkers through the grate system at the base of the reactor. To mitigate future occurrences, a modification of the grate system has been designed and implemented.

7.0 COST ASSESSMENT

7.1 COST MODEL

The cost model looks at several cost elements that are associated to the GEM product. Table 15 summarizes the costs per item.

Table 15. Cost elements associated with GEM WEC System.

Cost Element	Data Tracked during the Demonstration	Estimated Cost
Hardware Capital Costs	Based on base model commercial offering from MSW Power	\$1,100,00.00
Installation Costs	Labor and material required to install	\$47,000
Consumables	Estimates based on rate of consumables use during the field demonstration	\$13,000
Facility Operational Costs	Reduction in energy required versus baseline data	\$0.08/kWh electricity \$75/ton of waste disposal \$0.03/kWh heat
Maintenance	Frequency of required maintenance and labor and material per maintenance action	\$13,000
Hardware Lifetime	Estimated based on components degradation during demonstration	15 years
Operator Training	Estimate of training costs	\$15,000

7.2 COST DRIVERS

The major cost driver for the GEM product is the initial capital investment. With a purchase price of \$1,100,000 it is by far the highest cost. In terms of return on investment (ROI) cost drives, that depends on the cost of electricity, waste disposal, heating costs and needs/duty cycle and waste composition. It is recommended that the GEM be installed with a metal separation process (as is currently available in its commercial unit). This will reduce any metal contamination down to less than 1%. Consequently, this will help increase net power output closer to 600 kW/ton as well as provide an innocuous ash stream. Edwards AFB did perform preliminary metal testing for leachates to categorize the waste as hazardous or non-hazardous, they did not perform an actual leachate test. Because the metal going through this process was copper, nickel, steel, steel with chrome plating, brass, and stainless steel primarily, IST and MSW Power suggest that this material wouldn't trip any leachate requirements for disposal.

7.3 COST ANALYSIS AND COMPARISON

On average, under separate studies, the GEM has been demonstrated to produce >66 kW_e net electrical production, 182 kW_T heat production while consuming 3 tons of trash and converting it into 300 pounds of ash per day. Other direct costs include maintenance, consumable and diesel consumption costs. For the purposes of this analysis, the maintenance and consumable costs is defined as 5% of system purchase price. The GEM at Edwards AFB produced on average 50kW gross electrical output (net of 24 kW_e) and 65kW_T heat recovered. Ash output was approximately 10% or 600 pounds/day. It is important to note that because this product replaces energy requirements from the grid, there is no direct comparison to existing technology that the GEM would replace on site. Additionally, the cost model doesn't account for decreasing and eventually closing of the landfill site.

7.3.1 Payback Sensitivity Analysis

Typical utility and waste hauling costs have a significant impact on the payback period for the GEM WEC system. Figures 4 and 5 provide insight into the variability of the payback period as a function of electricity costs and waste disposal costs, respectively. For both scenarios, the following assumptions are made:

- Annual operation of 24 hours a day for 6 days a week; 7444 hours per year
- Waste throughput = 3 tons per day; 930 tons per year
- Average net outputs of 66 kW_e and 182 kW_T
- Average solid to gas conversion efficiency of 90%
- One-time costs of $1.1 million for the system, $47,000 for installation, and $15,000 for training
- Annual recurring costs of $13,000 for consumables and $13,000 for maintenance
- Baseline utility costs of $0.08/$kWh_e$, $0.03/$kWh_T$, and $75/ton waste disposal

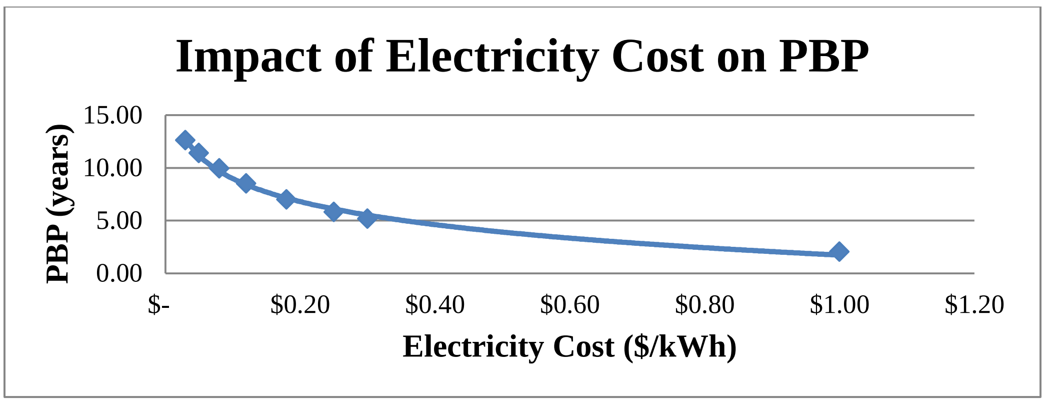

Figure 4. Impact of electricity cost on payback period.
(waste disposal cost fixed at $75/ton)

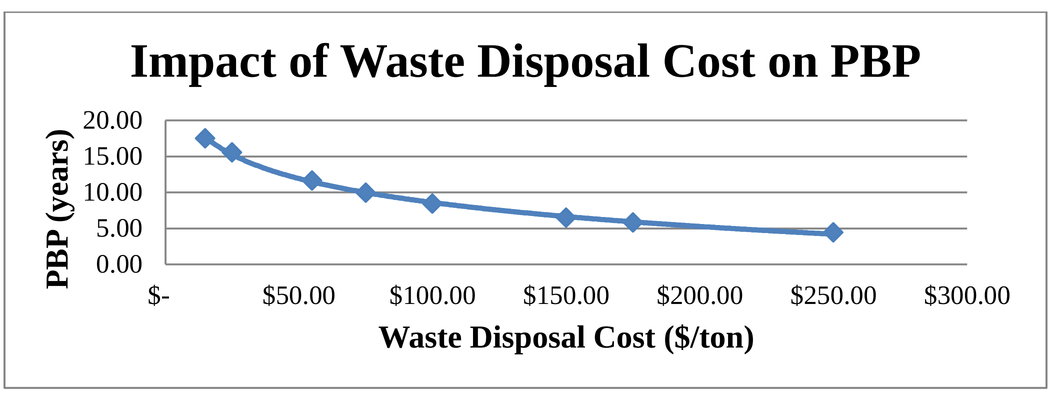

Figure 5. Impact of waste disposal cost on payback period.
(electricity cost fixed at $0.08/kWh)

7.3.2 Scalability Considerations

The GEM was designed with modularity in mind. While the system was demonstrated as a fully-containerized unit, containerization is not required, nor is it limited to the number of containers demonstrated. Use scenario must be considered prior to designing a solution beyond a 3 ton per day throughput. Surely, the simple inclusion of additional 3 ton per day systems can be considered; however, this would not enable enjoyment of economy of scale. Thus, scalability is best addressed at the subsystem level:

- ***SWP.*** The SWP is comprised of commercial off-the-shelf (COTS) and modified equipment that is responsible for converting bulk, co-mingled waste into waste-based fuel pellets. The waste is size reduced, conditioned, and pelletized to achieve this objective. The SWP can be scaled up to several tons per hour throughput without complication, thereby affording for a centralized "pellet plant" that feeds distributed gasification/generation modules. Scale down of the SWP would be a more difficult task, and the recommendation would be to either operate the SWP on a reduced duty cycle or have a centralized SWP feeding distributed gasification/generation modules.
- ***Gasification.*** A stratified downdraft gasifier is used to efficiently convert waste pellets into syngas. The system can be readily scaled down to the sub-ten pounds/hour level, although process economics would be questionable at this scale. Downdraft gasification certainly has upper limits for scale. A 10 ton/day throughput could be met with the current design approach, while throughputs above this would require a revisit of reactor design. All gas conditioning/clean-up equipment used is readily scaled up and down.
- ***Controls/Integration Backplane.*** The controls system and integration framework are highly flexible and are capable of accepting a variety of inputs.

In summary, it is conceivable that the system could be scaled down to sub-ton levels (process economics rather than engineering may be the limiting factor for determining the smallest scale of the system). The flexibility of the system to operate in a distributed fashion (i.e., central preprocessing and distributed gasification/generation) presents an option to address very high throughput (tons per hour) using the existing gasification module. While we have not done so, it is expected that the gasifier could be readily scaled to 10 ton/day throughput without diversion from the fundamental processing approach.

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8.0 IMPLEMENTATION ISSUES

Implementation of the demonstration activity at Edwards AFB experienced a number of delays and unforeseen complications. While the demonstration was ultimately executed, these issues did negatively impact the ability of the project to stay on schedule, within budget, and to meet all of the performance objectives. There were three major categories of issues encountered:

- Regulatory
- End-user concerns
- Site-specific shortcomings

8.1 REGULATORY ISSUES

Operation of the demonstration required permits from state and local authorities, an interconnection agreement with the local utility provider, and a license from the Base Commander. Acquiring a license to operate at Edwards AFB was a relatively straightforward activity. This required IST to submit a request to Edwards AFB with background on the project and basis for request. IST received the license (AFMC-ED-3-10-006) once a town hall meeting was held at the base and no objections were heard. Throughout the course of the project several extensions were received as required due to the delayed imposed by permitting issues.

Upon initial review of regulatory requirements with the team at Edwards AFB and the local regulatory body, it was determined that the only permit required for operation of the demonstration was an experimental exemption to be issued by the Eastern Kern Air Pollution Control District (EKAPCD). In March 2011, IST's request for an Experimental Research Exemption was approved, and the project received a EKAPCD designation number of 110114. With environmental permitting believed to have been addressed, IST moved forward with acquiring clearance to connect to the local grid at Edwards AFB. Unfortunately, the local utility provider, SCE, was obstructive and lacked responsiveness and full disclosure throughout the process. Although an interconnection application was submitted, this was ultimately abandoned as it became apparent that the application for this project had been bundled with a number of other alternative energy projects at the base. Were the project to stay the course with interconnection, further delay would have been required to accommodate a telemetry study as required due to the aggregate size of the projects.

Concurrent with the pursuit of interconnection approval, IST continued to pursue required accommodations at the site to ensure a successful operation. During the course of conversations and approval requests for various elements of the project, publicity for the project heightened. As a result, new stakeholders appeared requesting revisit of IST's permitting status. Corresponding conversations brought into question whether the project would represent a violation of Edwards AFB's landfill permitting due to the GEM WEC System being located at the landfill and thus representing a material change in use scenario from what was described in their permit. This revelation resulted in further delays and at one point put the project at risk of being shut down due to an initial ruling by CalRecycle that the project was not in the best interest of the public. However, IST lobbied with CalRecycle and ultimately Edwards AFB received a Project Permit Exemption from the Kern County Environmental Health Division of CalRecycle on March 19,

2012. In summary, the following regulatory approvals were required to operate the demonstration at Edwards AFB as planned:

- License to Operate at Edwards AFB
- Experimental Exemption from EKAPCD
- Permit Exemption from the Environmental Health Division of CalRecycle
- Generating Facility Interconnection Agreement with SCE

Future implementation of the GEM WEC system at a DoD or other installation would not be performed under an experimental exemption. Generally speaking, this would require a Title V permit. Under a Title V permit, the site is defined as either an area source or a major source. Table 16 summarizes the impact the GEM WEC system would have on existing site permit and the steps required to legally operate the GEM WEC. Permitting of the GEM under a full permit can be achieved across Federal and state regulations. Details of how those permits would be obtained are site specific and require Federal level of applicability as well as local state regulations (if applicable). Massachusetts is the only state in the Union that has a moratorium on "waste burning," which they have extended to gasification technologies (although the policy is currently being modified to include pyrolysis and gasification technologies).

Table 16. Summary of Title V permit implications associated with GEM WEC implementation.

Permit Type	Impact	Process
Title V major source	GEM emissions must be assessed and evaluated under current emissions across the permitted site against their allowable thresholds.	If the GEM does not cause the facility to exceed the thresholds, then a simple Title V modification to include the GEM on the permit would suffice. A major modification would need to occur if the GEM would increase threshold limits. This may be difficult to achieve; however, the GEM emissions on a ton/year basis is rather insignificant when compared to thresholds and limits of Major Title V permits.
Title V Area source	GEM emissions must be assessed and evaluated under current emissions across the permitted site against their allowable thresholds.	If the GEM trips the thresholds between an area source and a major source, a Title V major source permit must be obtained. If not, a modification to add the GEM to the existing Title V area source permit will be required.
State Regulations	Determine GEM applicability to local regulations	Every state has the right to have more stringent air quality regulations than the EPA methods. IST and MSW Power have not prepared an exhaustive list of all the states regulations. Additionally, the states in which the two companies have experience do not have regulations for small scale gasification units. Most states have deferred to EPA regulations.

It is a general rule of thumb that the Northeast region of the United States (primarily Massachusetts) and California have the toughest regulations for permitting such a unit. Most other states have deferred to Federal regulations for permitting. The GEM has been classified by the EPA as an Other Small Waste Incinerator (OSWI) and can be permitted according to 40 Code of Federal Regulations (CFR) 60 subpart EEEE (which varies depending on the system's ability to produce electricity or hot water/heat). MSW Power has experience in obtaining a letter from the EPA approving the GEM operation at an institutional site (Plymouth County Correctional Facility, Plymouth, Massachusetts).

While an exhaustive analysis of each state and municipality was not practical given the time and funding priorities for this project, some understanding of those states that can be expected to be most receptive to waste-to-energy (WTE) technologies was gained. The following states had active WTE operations in 2011: California, Connecticut, Delaware, Florida, Hawaii, Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Oklahoma, Oregon, Pennsylvania, Utah, Virginia, and Washington. The presence of active WTE operations is not in and of itself indicative of a region that would be receptive to new WTE activities. An understanding of any local, county, or state moratoriums on expansion must be gained prior to targeting a specific site for technology transfer.

8.2 END-USER CONCERNS

At the onset of the project, it was well-documented and known that the GEM WEC System was not sufficiently sized to process all of the waste heading to Edwards AFB's landfill. It was generally well-excepted that the GEM represented a potential means of slowing the rate at which the landfill was filled, and could possibly aid in landfill extension through processing of waste already in the landfill. However, as it was not a total solution, detractors did exist within the stakeholder community. As a result of the demonstration, three primary sentiments were observed as it pertained to future use of the GEM at Edwards AFB:

1. ***Fear of the unknown.*** The GEM represents a marked shift in waste management paradigm, and as such is inherently controversial. Observers characterized as under-informed and/or passersby were noted to exhibit some apprehension over the use of a thermal conversion process to address waste burden. As a technology without documented track record, some expressed concern over safety and environmental impact.
2. ***Ash quality.*** In other studies, the GEM has been shown to produce ash streams that are below contaminant threshold for classification as hazardous waste (i.e., innocuous and suitable for landfill disposal). However, due to the unexpected high metal content and lack of active metal separation to address it, ash analysis indicated the GEM ash produced at Edwards AFB to be hazardous (see Appendix E in the Final Report).
3. ***Cost benefit.*** As noted in this report, the reduced throughput experienced due to composition of the waste stream yields a poor cost benefit result for the GEM at Edwards AFB. In the absence of other compelling factors, cost (and specifically ROI) will drive decisions regarding suitability of the GEM for candidate sites.

8.3 SITE-SPECIFIC SHORTCOMINGS

Due to delays imposed by regulatory issues, the waste stream at Edwards AFB experienced some change between project kick-off and demonstration initiation. Specifically, a major detractor of demonstration results was the high metal content of the waste stream. Because a large portion of the waste diverted for use in this demonstration coming from residential streams at the base (as opposed to cafeteria or industrial streams), the waste was observed to contain a broad range of items including hazardous waste, electronic waste, and wiring that would not typically find its way to landfill if derived from a cafeteria or industrial source. As a result, the throughput of the gasifier was much lower due to both reduced combustible content in the waste and some jamming at the pellet mill. This, coupled with end-user concerns, ultimately led to the system not being retained by Edwards AFB for continued use.

8.4 TECHNOLOGY OUTLOOK

The GEM technology was originally developed for the processing of feeding wastes in the combat theatre. This type of feedstock contained by weight 44% food, 42% paper/cardboard and 14% plastic. This blend of material was used for optimizing the GEM process. Edwards AFB waste contained both office and residential wastes, with residential being the predominant weight fraction. The waste that was tested at Edwards AFB had several tough components for processing. First, the waste was high in moisture, reducing the processing rate through the drying in order to properly dry the material. MSW Power has the ability to use a larger drying bed, which would increase the processing rate of high moisture feedstock. Additionally, Edwards AFB waste contained significant amount of inorganic material including a substantial amount of metals. These metals were in the form of aluminum and steel cans, miscellaneous household items, and wiring. MSW Power encourages that these items be recycled. However, it is naïve to think that metal objects would not enter the waste stream. On MSW Power's second generation GEM unit, an inline metal separation unit removes 99% of ferrous, non-ferrous, glass and other ceramic materials from the waste material. This increases system robustness and output. The Edwards AFB waste stream had samples that returned with as high as 30% by weight of inorganic material in the pellet. This reduces the BTU content and processing rate of the waste pellet through the reactor significantly. At 30% inorganics in the pellet, the syngas BTU content is below 100 BTU/cubic foot. Additionally, the high amount of inorganic material in the reactor slowed down the processing rate, as the control system had not previously seen inorganic content that high. By reducing the metals and glass components the GEM would have operated closer to its targeted operation parameters.

Therefore, when evaluating sites for future GEM installations, it is important to look at the following criteria:

- ***Source of material.*** Cafeteria and an office waste are ideal due to composition. Residential waste contains a significant amount of inorganic material that should be considered for recycling rather than processing through a waste to energy system.
- ***Moisture content.*** The GEM can handle a wide range of moisture contents; however, proper selection of system variant requires a solid understanding of the max, average and minimum values of moisture content of the waste. Depending on the typical moisture content, an appropriate preprocessing subsystem can be specified.
- ***Understanding inorganic material.*** MSW Power has designed preprocessing subsystem options featuring a metal separation process that can eliminate a substantial amount of inorganic material prior to the pelletizing process. This subsystem option should be included in future DoD installations.

- ***Heat Requirements.*** In order to optimize ROI, sites having the ability to make use of the waste heat captured by the system are preferred. The heat can be used for heating, ventilation, and air conditioning (HVAC) or hot water applications.
- ***Costs.*** For an attractive ROI, site operating costs should at least meet the following, which would result in a PBP of less than 7 years: Disposal costs > \$100/ton; Electrical costs > \$.08/kWh; Heating Costs > \$0.05/kW_T.

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APPENDIX A

POINTS OF CONTACT

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